Extraction of Antenna Gain from Path Loss Model for In-Body Communication

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Abstract

In this letter we propose for the first time an in-body path loss model for homogeneous human muscle and head tissue that is independent of the antennas for in-body communication at 2.45 GHz. The path loss model obtained can be used to design in-body communication systems at 2.45 GHz.

I. Introduction

A wireless body area network (WBAN) consists of nodes that communicate wirelessly and are located on or in the body of a person. To obtain optimal communication between the nodes placed within the human body better understanding of propagation loss is required for the development of WBAN. This need arises as the human body is a lossy medium which considerably attenuates the electromagnetic waves traveling from the transmitter (Tx) to the receiver (Rx). Up to now, in literature various PL models have been proposed for in-body propagation but the gains of the Tx and Rx antennas are always included in the models, limiting the general usability [1]. In this letter, we make for the first time in-body path loss (PL) independent of the antenna by extracting the antenna gains from the PL for two different types of antennas within homogeneous lossy human muscle and head tissue.

II. Method

Wave propagation is investigated in both human muscle tissue (relative permittivity $\epsilon_r = 50.8$ and conductivity $\sigma = 2.01$ S/m [2]) and head tissue ($\epsilon_r = 42.53$ and $\sigma = 1.51$ S/m [2]) using two pairs of insulated antennas at 2.45 GHz. Insulated antennas are selected instead of bare antennas because the insulated antenna prevents the leakage of conducting charges from the antenna and also reduces the sensitivity of the entire distribution of current to the electrical properties of the ambient medium [3].

The first pair of antennas consist of two identical insulated dipoles where the dipole arms are perfect electric conductors (PEC) surrounded by an insulation made of polytetrafluoroethylene (PTFE) ($\epsilon_r = 2.07$ and $\sigma = 0$ S/m). The length of the dipole arms is chosen to be ℓ_1 = 3.9 cm (henceforth addressed as $antenna_{(\lambda/2)}$) such that the antenna resonates at 2.45 GHz. The resonance appears when the antenna is equal to half the wavelength in a homogeneous medium equivalent to the combination of the insulation and the muscle tissue medium. Hence, λ_{res} = 7.8 cm (where, λ_{res} is the wavelength at which resonance occurs) and we can derive the equivalent permittivity $\epsilon_{r,equiv} = 2.45$ which is closer to the permittivity of the insulation.

The second pair of antennas are also dipole antennas insulated with the same insulation of PTFE. The length of the dipole arms ℓ_2 = 7.8 cm (henceforth addressed as $antenna_{(\lambda)}$).

Simulations are carried out for the setup of the insulated antennas in human muscle and head tissue medium for a separation of 30 cm between the Tx and the Rx using FEKO, a method of moments (MoM) program. For accurate modelling in the MoM tool, segmentation rules are adhered (segment length = λ_{res}/12, edge length = λ_{res}/12). The source used is a current source.

III. Results

A. Gain of the antenna in conductive medium

The gain of the antenna in free space is defined as the ratio of radiation intensity in a particular direction to the radiation intensity of an isotropic antenna [4]. However, the radiation intensity becomes distance dependent in a conducting medium. To make the antenna gain distance independent in a conducting medium, it can be expressed as follows [4]:

$$G = \left(4\pi R g^2\right)/R_r \tag{1}$$

where, G is the gain of the antenna in the conductive medium and g is a function involving the parameters of the medium, R is the intrinsic resistance and is equal to $\sqrt{\omega\mu/2\sigma}$ and R_r is the radiation resistance. Also, ω = $2 \cdot \pi \cdot f$ = angular frequency [rad/sec], f= frequency = 2.45 GHz, μ = permeability of the lossy medium, and σ = conductivity of the lossy medium [S/m].

Further, g is defined [4] as follows:

$$g = (|H| d\ e^{d/\delta})/I_i \tag{2}$$

where, $|H|$ is the magnitude of the magnetic field in [A/m] taken in the maximum field direction of the antenna under consideration at distance d, δ is the skin depth in [m], I_i is the input current in [A] and d is the distance in [m].

1) Gain of $antenna_{(\lambda/2)}$ and $antenna_{(\lambda)}$ in muscle and head tissue: The gain of the $antenna_{(\lambda/2)}$ and $antenna_{(\lambda)}$, henceforth referred to as $G_{(\lambda/2)}$ and $G_{(\lambda)}$ respectively, in the muscle and head tissue is obtained using (1) and is shown in Fig. 1. $G_{(\lambda)}$ is 10.7 dBi and 10.3 dBi and $G_{(\lambda/2)}$ is 8.7 dBi and 8.1 dBi in the muscle and head tissue, respectively. The values of the gain selected are the asymptotic values obtained at large distance where it is more or less constant for both the head and muscle tissue. Fig. 1 shows that $G_{(\lambda/2)}$ and $G_{(\lambda)}$ are independent of distance after 80 cm and 45 cm in the muscle and head tissue, respectively. $|H|$ is obtained from the simulations, I_i = 1 A, δ for the muscle and head tissue is 7.2 mm and 8.3 mm respectively.

B. Path Loss

PL between a pair of antennas is the ratio of transmitted power to the received power in decibels [5]:

$$PL|_{dB} = 10 \cdot \log(P_T G_T G_R / P_R L_T L_R)\ , \tag{3}$$

where P_T = transmit power , P_R = received power, G_T = transmitter antenna gain, G_R = receiver antenna gain, L_T = feeder loss at transmitter, L_R = feeder loss at receiver. (3) can be written as follows when L_T = L_R = 0:

$$PL_{excl}|_{\mathrm{dB}} = P_T|_{dB} - P_R|_{dB} + G_T|_{dBi} + G_R|_{dBi} = -|S_{21}|_{dB} + G_T|_{dBi} + G_R|_{dBi}\ , \tag{4}$$

where, $|S_{21}|_{dB}$ is the forward transmission coefficient. Current literature [1] defines the in-body path loss (PL_{incl}), which includes the gain and is thus antenna dependent, as $1/|S_{21}|^2$ with respect to 50 Ω when the generator at the Tx has an output impedance of 50 Ω and the Rx is terminated with 50 Ω, this allows to regard the setup as a two-port circuit for which we determine $|S_{21}|_{\mathrm{dB}}$ with reference impedances of 50 Ω at both ports. PL_{incl} is defined as follows:

$$PL_{incl}|_{\mathrm{dB}} = (P_T/P_R) = -10 \ \log_{10} |S_{21}|^2 = -|S_{21}|_{\mathrm{dB}} \ , \tag{5}$$

where, P_T = input power at port 1 and P_R = power received at port 2 in a two-port setup.

PL_{excl} is now defined as the actual PL, i.e. excluding the gains and thus antennas independent [5]. The Tx and the Rx here are identical (Section II) hence the gain of the Tx and Rx are the same. PL_{excl} is then calculated as follows from (4):

$$PL_{excl}|_{\mathrm{dB}} = PL_{incl}|_{\mathrm{dB}} + 2G_{\mathrm{dBi}}, \tag{6}$$

where G is the gain of the Tx and Rx antenna in dBi in the conductive medium according to (1).

Figs. 2 and 3 show the PL_{incl} and PL_{excl} of both the antennas in muscle and head tissue, respectively. The gain obtained at large distance (Fig. 1, Section. III-A) is excluded from the path loss using (6). By excluding the gain, PL becomes antenna independent: mean deviation between PL_{excl} of $antenna_{(\lambda)}$ and PL_{excl} of $antenna_{(\lambda/2)}$ are only 1.53 dB and 1.77 dB in the muscle and the head tissue, respectively. Figs. 2 and 3 clearly show that PL_{incl} as used previously in literature, is antenna dependent with deviations up to 7-8 dB in the muscle and head tissue. The deviation in PL_{excl} between $antenna_{(\lambda/2)}$ and $antenna_{(\lambda)}$ exists only up to a certain distance (around 26 cm) after which the PL merges because we apply the gain obtained at large distance to the distances close to the antennas showing acceptable deviations. We show here that using (1) and (6) we are able to define PL as it should be, namely antenna independent.

This has also been validated for different antenna and the results obtained were in accordance to that of the insulated dipole antennas

C. Model for PL

In this section, we propose a generalized model based on the simulation results for both the antennas in muscle and head tissue. The PL model as a function of distance in human muscle and head tissue at 2.45 GHz is as follows:

$$PL_{excl}|_{\mathrm{dB}} \equiv PL|_{\mathrm{dB}} = (10\ \log_{10} e^2)\ \alpha\ d + C|_{\mathrm{dB}} \tag{7}$$

where the parameters α is the attenuation constant $[\frac{1}{cm}]$, $C|_{\mathrm{dB}}$ is the constant, and d is in cm. $(10\ \log_{10} e^2)$ equals 8.68 dB and shows the exponential behaviour of the PL. The parameter values for antenna independent PL are shown in Table I and are obtained by using a least square-error method. The attenuation constant in the muscle tissue is higher than in the head tissue as the conductivity in the muscle tissue is higher. Also, the attenuation constant obtained for the muscle and the head tissue agrees well with the attenuation constant for plane wave which is 0.52 $[\frac{1}{cm}]$ and 0.43 $[\frac{1}{cm}]$, respectively. In Figs 2 and 3 the PL_{excl} in head and muscle tissue (for $antenna_{(\lambda/2)}$ and $antenna_{(\lambda)}$) are fitted to the PL model of (7) with a mean deviation lower than 1.5 dB. Thus, the proposed PL model is an excellent fit and can be used for any antenna in link budget calculations by introducing the antenna gain in tissue.

D. Conclusions

The path loss between different types of insulated dipole antennas is investigated at 2.45 GHz in homogeneous human muscle and head tissue and for the first time an in-body path loss model independent of the antennas is derived by excluding the gain of the antennas. The PL model can thus be used to design any in-body communication system in muscle tissue and head tissue.

References

[1] A. Alomainy and Y. Hao, "Modeling and characterization of biotelemetric radio channel from ingested implants considering organ contents," *Antennas and Propagation, IEEE Transactions*, vol. 57, pp. 999–1005, April 2009.

[2] FCC OET Bulletin 65, Revised Supplement C, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields," Federal Communication Commission, Office of Engineering and Technology, June 2001.

[3] R. W. P. King, G. S. Smith, M. Owens, and T. T. Wu, *Antennas in matter fundamentals, theory and applications*. Cambridge, MA : MIT Press, 1981.

[4] R. Moore, "Effects of a surrounding conducting medium on antenna analysis," *Antennas and Propagation, IEEE Transactions*, vol. 11, pp. 216–225, May 1963.

[5] S. R. Saunders, *Antennas and Propagation for Wireless Communication Systems*. Wiley and Sons, 1999.

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TABLE I

PARAMETER VALUES AND STANDARD DEVIATIONS OF THE FITTED MODELS FOR PL_{dB} IN HUMAN MUSCLE AND HEAD TISSUE.

Tissue	α [$\frac{1}{cm}$]	C [dB]
Head Tissue	0.49	2.1
Muscle Tissue	0.58	1

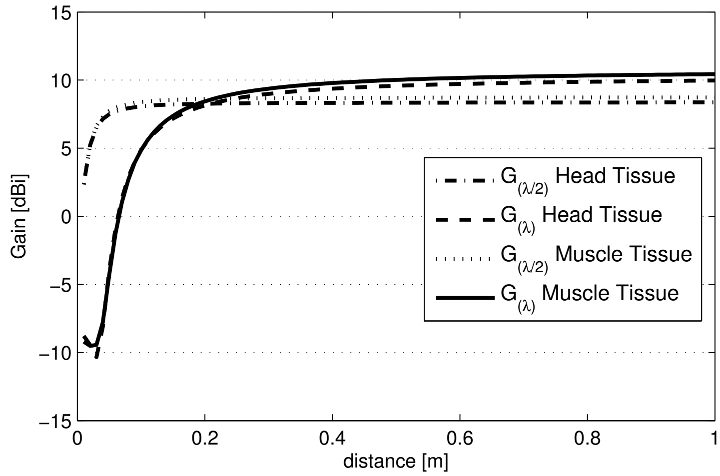

Fig. 1. Gain of the insulated dipole antennas in head and muscle tissue.

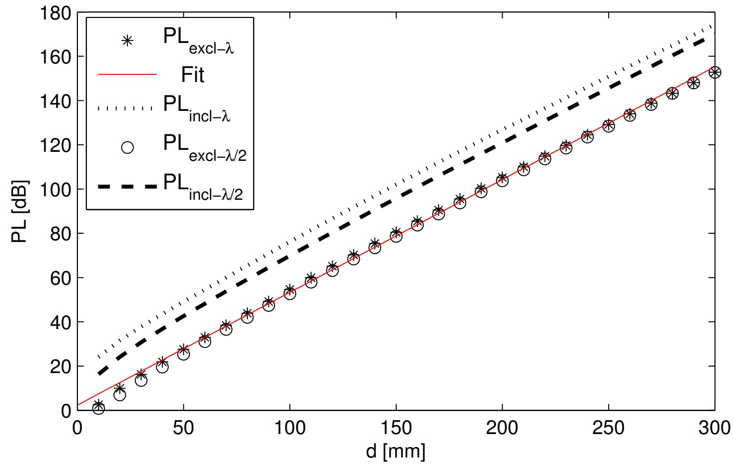

Fig. 2. PL of the insulated dipole including and excluding the gain in muscle tissue.

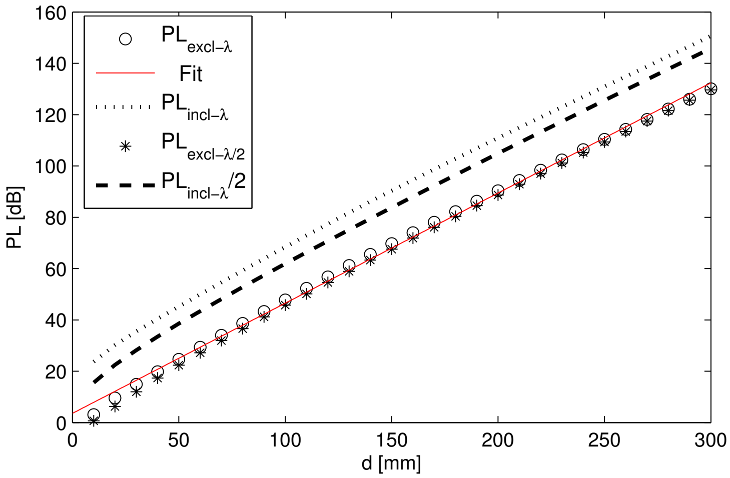

Fig. 3. PL of the insulated dipole including and excluding the gain in head tissue.